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(11)

EP 1 041 668 A2

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:
04.10.2000 Bulletin 2000/40

(51) Int Cl.7: H01P 7/06

(21) Application number: 00302698.6

(22) Date of filing: 30.03.2000

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU
MC NL PT SE
Designated Extension States:
AL LT LV MK RO SI

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(30) Priority: 31.03.1999 KR 9911267

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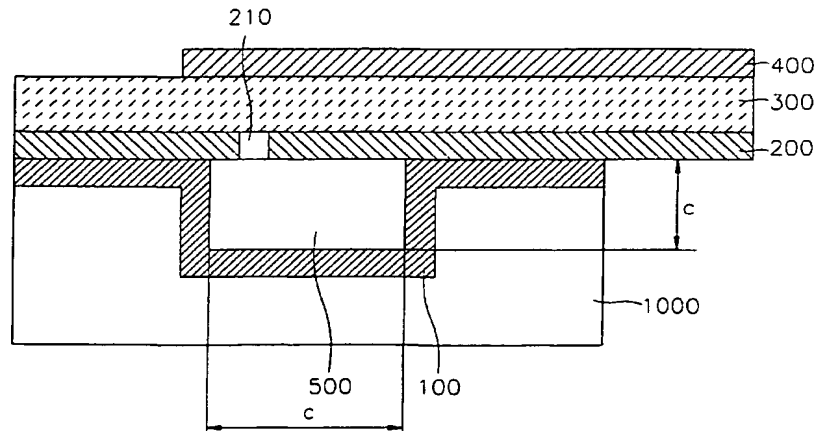
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(54) Cavity resonator for reducing phase noise of voltage controlled oscillator

(57) There is provided a cavity resonator for reducing the phase noise of electromagnetic waves output from a monolithic microwave integrated circuit (MMIC) voltage controlled oscillator (VCO) by utilizing a semiconductor (e.g., silicon, GaAs or InP) micro machining technique. In the cavity (500), instead of an existing metal cavity, a cavity, which is obtained by micro machining silicon or a compound semiconductor, is coupled to a

microstrip line (400) to allow the cavity resonator to be adopted in a reflection type voltage controlled oscillator. A coupling slot (210) is formed by removing a predetermined size of the part of an upper ground plane film (200) of a cavity facing to the microstrip line (400). Consequently, the cavity resonator reduces the phase noise of microwaves or millimetre waves which are output from a voltage controlled oscillator.

FIG. 2C



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Description

[0001] The present invention relates to a cavity resonator for reducing the phase noise of electromagnetic waves output from a monolithic microwave integrated circuit (MMIC) voltage controlled oscillator (VCO) by utilizing a semiconductor (e.g., silicon, GaAs or InP) micro machining technique.

[0002] Since a microwave/millimetre wave MMIC VCO, which does not use a cavity, outputs electromagnetic waves having large phase noise, the MMIC VCO is not appropriate for use in a radar system using a frequency modulating continuous wave (FMCW). Recently, dielectric disks or transmission lines have been utilized as resonators to reduce phase noise. However, dielectric resonators for millimetre waves are very expensive and are difficult to mass produce because the frequency at which resonance occurs depends on the locations of dielectric resonators, and thus it is difficult to determine the locations of dielectric resonators in an MMIC substrate. Moreover, the Q-factor of transmission line resonators is too small to reduce phase noise.

[0003] FIGS. 1A and 1B are a plan view and a sectional view, respectively, of a conventional cavity resonator, and show a structure of an X-band micromachined resonator which is disclosed in IEEE Microwave and Guided Wave Letters, Vol. 7, pp. 168, 1997. The conventional cavity resonator is structured such that two microstrip lines 30 are coupled to a cavity 20 through two slots 10. Such structure implements a transmission type resonator having an input port and an output port. Since the transmission type resonator has a more complicated feed structure than a reflection type resonator, it is difficult to design the transmission type resonator having a larger Q-factor.

[0004] According to the invention there is provided a cavity resonator for reducing the phase noise of a voltage controlled oscillator. The cavity resonator includes a cavity including a lower metal film, which is formed by etching a semiconductor in a rectangular parallelepiped structure and depositing a conductive film, and an upper ground plane metal film, which is formed to cover the top of the rectangular parallelepiped structure of the lower metal film. A microstrip line is formed to expand from one end of the cavity across the other end of the cavity in a predetermined width so as to serve as a waveguide. The microstrip line is disposed a uniform predetermined distance from the upper ground plane metal film of the cavity. A slot is formed to face the microstrip line by removing a predetermined size of the part of the upper ground plane metal film.

[0005] The cavity resonators of the invention reduce the phase noise of electromagnetic waves output from a monolithic microwave integrated circuit (MMIC) voltage controlled oscillator (VCO) by coupling a silicon micromachined cavity, which has a large Q-factor, to a microstrip line such that the silicon micromachined cavity can be employed in a reflection type VCO.

[0006] Two slots may be provided, which are formed by removing a predetermined size of the part of the upper ground plane metal film, the two slots positioned opposite the microstrip line; and

a matching resistor is inserted into a portion of the microstrip line, the portion being formed by removing a predetermined width of part of the microstrip line corresponding to one end of the cavity.

[0007] Preferably, the lower metal film, the upper ground metal film and the microstrip line are formed of a conductor selected from the group consisting of gold (Au), silver (Ag) and copper (Cu). The predetermined distance between the microstrip line and the upper ground metal film is maintained by interposing a substrate formed of a semiconductor or an insulating material between them.

[0008] Examples of the present invention will now be described in detail with reference to the attached drawings in which:

FIGS. 1A and 1B are a plan view and a sectional view, respectively, of a conventional cavity resonator;

FIG. 2A shows the shape of a cavity which is adopted in a cavity resonator according to the present invention;

FIG. 2B shows a plan view of a 1-slot reflection type cavity resonator according to the present invention and a sectional view of the 1-slot reflection type cavity resonator taken along the line B-B';

FIG. 2C is a sectional view of the 1-slot reflection type cavity resonator of FIG. 2B taken along the line A-A'; and

FIG. 3 is a graph for showing the frequency characteristic in the 1-slot reflection type cavity resonator depicted in FIGS. 2B and 2C;

FIG. 4 is an S11 parameter of electromagnetic waves output from the 1-slot reflection type cavity resonator depicted in FIGS. 2B and 2C;

FIGS. 5A and 5B are a plane view and a sectional view, respectively, of a 2-slot cavity resonator according to the present invention; and

FIG. 6 shows an S11 parameter of electromagnetic waves output from the 2-slot cavity resonator depicted in FIGS. 5A and 5B.

[0009] The phase noise of oscillators is one of the most important factors influencing the performance of transmitting and receiving systems. The resonance frequency of a rectangular parallelepiped metal cavity, as shown in FIG. 2A, is expressed as the following formula. Reference characters *a*, *b* and *c* indicate the width, depth and length, respectively, of the rectangular parallelepiped metal cavity.

$$f_0 = \frac{v_{ph}}{2} \sqrt{\left(\frac{l}{a}\right)^2 + \left(\frac{m}{b}\right)^2 + \left(\frac{n}{c}\right)^2}$$

Here, V_{ph} is the phase velocity inside the cavity and l , m and n are integers indicating resonance modes. There are three kinds of Q factors used for measuring the performance of a cavity. The three Q factors are defined as follows:

unloaded Q (Q_U): $Q_U = f_0/\Delta f = (2\pi f_0)W/P_{loss}$

loaded Q (Q_L): unloaded Q considering the input and output load

external Q (Q_E): $1/Q_E = 1/Q_L - 1/Q_U$.

Here, f_0 is a resonance frequency, W is stored energy, and P_{loss} is lost energy. Phase noise is inversely proportional to the square of the Q value of a resonator so that a resonator having a large Q value must be used to reduce phase noise. To excite the resonator, electromagnetic wave energy is coupled to the cavity of the resonator using a coaxial cable, a waveguide or a microstrip line, or through an aperture. As shown in FIGS. 2B and 2C, a cavity resonator of the present invention has a reflection type structure in which a silicon micromachined cavity having a large Q -factor is coupled to a microstrip line so that the cavity resonator can be utilized in a reflection type voltage controlled oscillator. While a conventional transmission type cavity resonator has input and output ports, a cavity resonator of the present invention is a reflection type cavity resonator having a single port. The reflection type cavity resonator has a simpler feed structure than the transmission type cavity resonator so that it is possible to fabricate a resonator having a larger Q -factor in the present invention. The structure of such cavity resonator according to the present invention, will now be described in detail.

[0010] FIGS. 2B and 2C are a plan view and a sectional view, respectively, for showing the schematic structure of a 1-slot reflection type cavity resonator. As shown in FIGS. 2B and 2C, the cavity resonator of the present invention basically has a structure in which, instead of a metal cavity, a cavity 500, which is formed of a silicon or compound semiconductor substrate 1000 using a micro machining technology, is coupled to a microstrip line 400. The cavity 500 includes a lower cavity film 100, which is a rectangular parallelepiped structure defined by a metal film such as a gold (Au) film and a ground plane film 200, which covers the top of the lower cavity film 100. The microstrip line 400 is formed of a conductive film having an excellent conductivity such as a gold (Au) film, a silver (Ag) film or a copper (Cu) film to serve as a waveguide at a predetermined distance from the upper ground plane film 200 of the cavity 500. A substrate 300 of Si, glass or a compound semiconductor is interposed between the microstrip line 400 and the upper ground plane film 200 of the cavity 500 to maintain the predetermined distance between the waveguide of the microstrip line 400 and the upper ground plane film 200. Through holes 700a are formed on the substrate 300 at both sides of the microstrip line 400. Grounding pads 700 are formed over the through holes 700a to be connected to the upper ground plane film 200. The microstrip line 400 stops near one end of

the cavity 500. A single slot 210 facing the microstrip line 400 is formed on the upper ground film 200 near the one end, thereby guiding electromagnetic waves, which have been guided along the waveguide including the upper ground plane film 200 and the microstrip line 400, to the cavity 500 and thus generating resonance.

[0011] The 1-slot reflection type cavity resonator having such structure draws a signal output from a VCO to a microstrip line 400 formed of gold and generates an electromagnetic wave mode in the cavity 500 using the electromagnetic wave coupling between the microstrip line 400 and the cavity 500. The electromagnetic wave coupling between the microstrip line 400 and the cavity 500 is established using the slot 210 which is appropriately formed. The electromagnetic waves at a stable mode in the cavity 500 are transferred to the microstrip line 400 through the slot 210 and output to an antenna. In other words, in a 1-slot cavity resonator as shown in FIGS. 2B and 2C, electromagnetic waves output from a VCO progress toward a slot along a microstrip line and are coupled to a cavity near the slot. Then, the electromagnetic waves excite a dominant cavity mode TE_{110} in the cavity so that electromagnetic waves having stabilized resonance frequency are output through the microstrip line.

[0012] FIG. 3 shows a frequency characteristic curve illustrating a frequency characteristic in the 1-slot reflection type cavity resonator described above. FIG. 4 shows an S11 parameter of the output electromagnetic waves of the 1-slot reflection type cavity resonator. Generally, a monolithic microwave integrated circuit (MMIC) voltage controlled oscillator (VCO) outputs electromagnetic waves having large phase noise so that the MMIC VCO is difficult to apply to a radar system using FMCW, but the 1-slot reflection type cavity resonator according to the present invention can greatly reduce the phase noise of the VCO.

[0013] FIGS. 5A and 5B are a plan view and a sectional view, respectively, of a 2-slot cavity resonator. The 2-slot cavity resonator is obtained by making the above embodiment of a 1-slot reflection type cavity resonator into a transmission type. The operational principle of the 2-slot cavity resonator is the same as that of the embodiment shown in FIGS. 2B and 2C. The 2-slot cavity resonator has a $50\ \Omega$ matching resistor 600, which attenuates electromagnetic waves having frequencies other than a resonance frequency, at a portion in the microstrip line 400, the portion which corresponds to the one end of the cavity 500. The 2-slot cavity resonator also has two slots 220 on the upper ground plane film 200, facing each other at both sides of the microstrip line 400. Those members which are designated by the same reference numerals as those of FIGS. 2B and 2C are formed of the same materials as in the 1-slot reflection type cavity resonator in FIGS. 2B and 2C. FIG. 6 shows an S11 parameter characteristic of electromagnetic waves output from the 2-slot cavity resonator which is a second embodiment of the present invention. It can

be seen from the result that the 2-slot cavity resonator is not as good as the 1-slot reflection type cavity resonator.

[0014] As described above, in a cavity resonator for reducing the phase noise of a voltage controlled oscillator according to the present invention, instead of an existing metal cavity, a cavity, which is obtained by micro machining silicon or a compound semiconductor, is coupled to a microstrip line to allow the cavity resonator to be adopted in a reflection type voltage controlled oscillator. A coupling slot is formed by removing a predetermined size of the part of an upper ground plane film of a cavity facing to the microstrip line. Consequently, the cavity resonator of the present invention reduces the phase noise of microwaves or millimetre waves which are output from a voltage controlled oscillator.

Claims

1. A cavity resonator for reducing the phase noise of a voltage controlled oscillator, the cavity resonator comprising:

a cavity (500) including a lower metal film (100), which is formed by etching a semiconductor (1000) in a rectangular parallelepiped structure and depositing a conductive film, and an upper ground plane metal film (200), which is formed to cover the top of the rectangular parallelepiped structure of the lower metal film (100); a microstrip line (400) which is formed to expand across the cavity (500) in a predetermined width so as to serve as a waveguide, the microstrip line (400) being disposed a uniform predetermined distance from the upper ground plane metal film (200) of the cavity; and a slot (210) which is formed to face the microstrip line (400) by removing a predetermined size of the part of the upper ground plane metal film (200).

2. The cavity resonator of claim 1, wherein two slots (220) are provided which are formed by removing a predetermined size of the part of the upper ground plane metal film (200), the two slots positioned opposite the microstrip line (400); and a matching resistor (600) is inserted into a portion of the microstrip line (400), the portion being formed by removing a predetermined width of part of the microstrip line (400) corresponding to one end of the cavity.
3. The cavity resonator of claim 1 or 2, wherein the lower metal film (100) and the upper ground metal film (200) are formed of a conductor selected from the group consisting of gold (Au), silver (Ag) and copper (Cu).

4. The cavity resonator of claim 1, 2 or 3, wherein the microstrip line (400) is formed of a conductor selected from the group consisting of gold (Au), silver (Ag) and copper (Cu).

5. The cavity resonator of any preceding claim, wherein the predetermined distance between the microstrip line (400) and the upper ground metal film (200) is maintained by interposing a substrate (300) formed of a semiconductor or an insulating material between them.

6. The cavity resonator of claim 5, further comprising:

through holes (700a) which are formed on the substrate (300) for maintaining the distance, at both sides of the microstrip line (400); and grounding metal pads (700) which are formed to be connected to the upper ground plane metal film (200) through the through holes (700a).

7. The cavity resonator of claim 5 or 6, wherein the semiconductor is silicon (Si) or a compound semiconductor.

8. The cavity resonator of claim 5 or 6, wherein the insulating material is glass.

FIG. 1A (PRIOR ART)

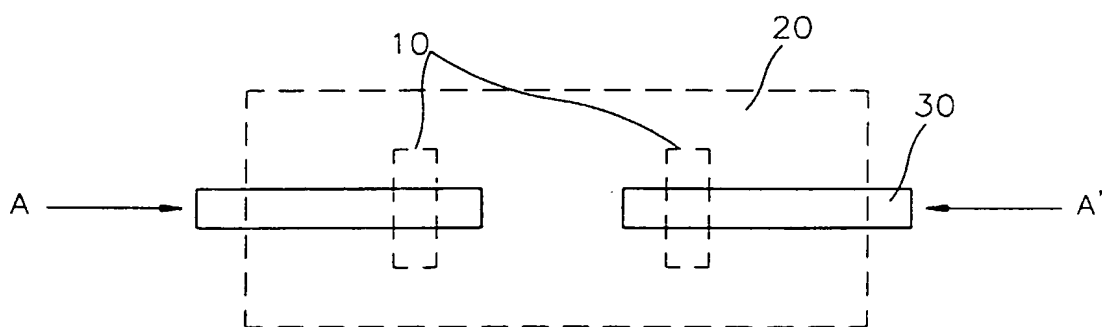


FIG. 1B (PRIOR ART)

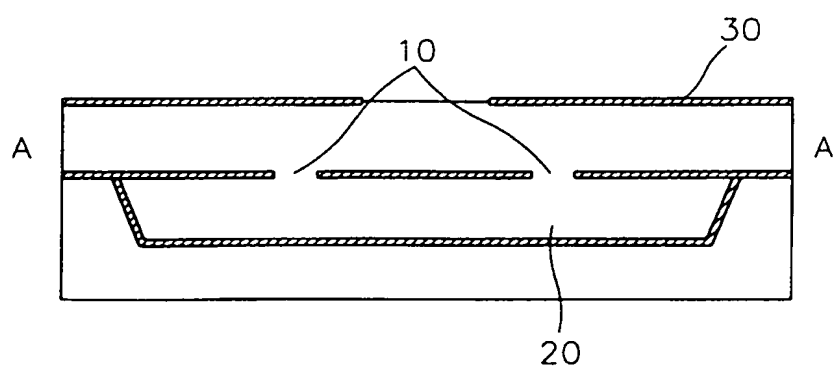


FIG. 2A

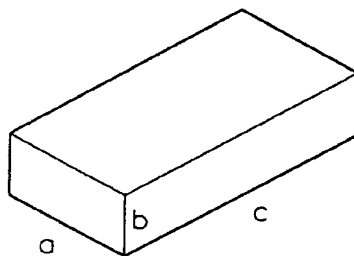


FIG. 2B

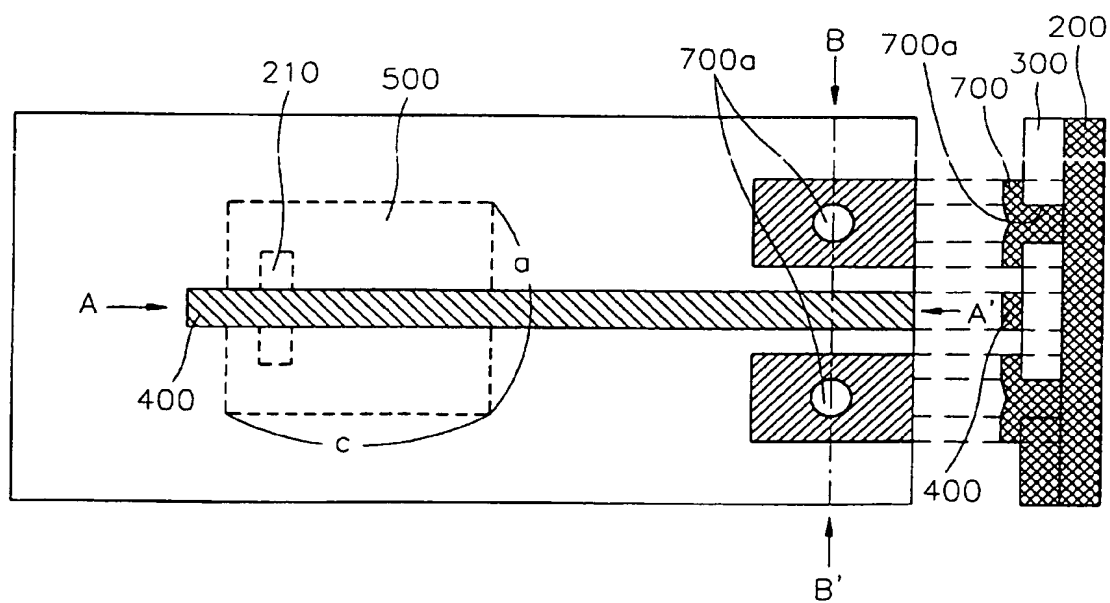


FIG. 2C

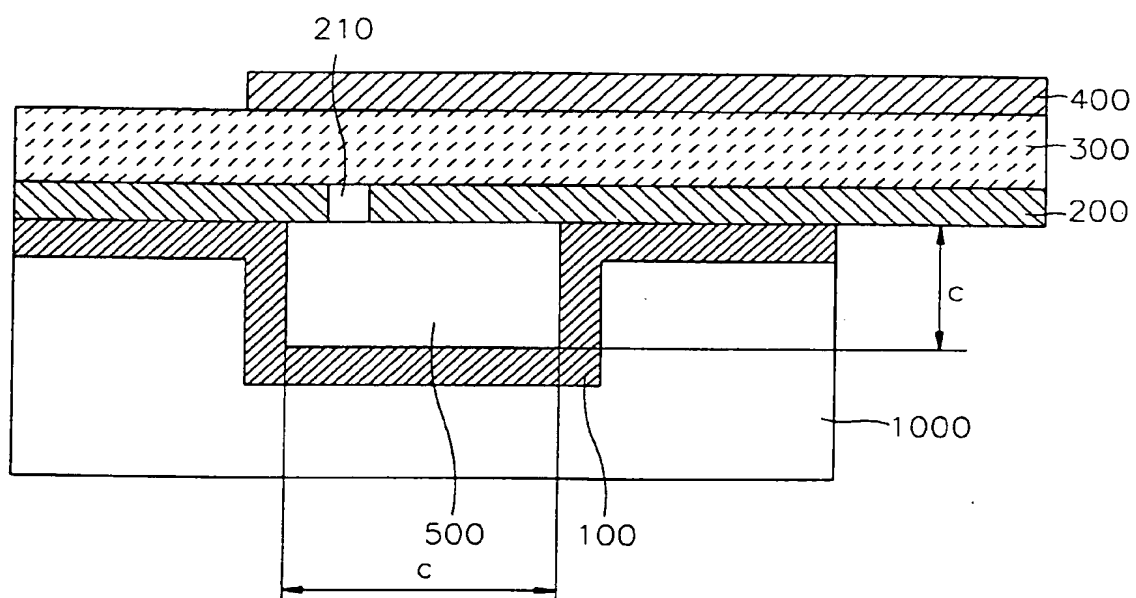


FIG. 3

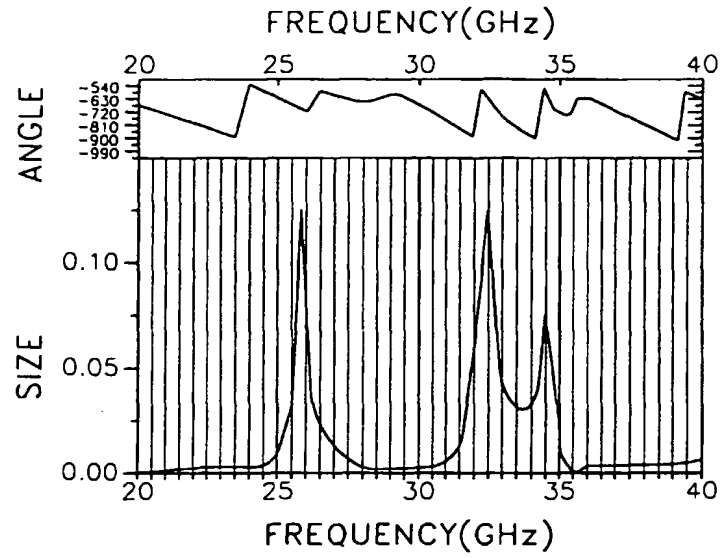


FIG. 4

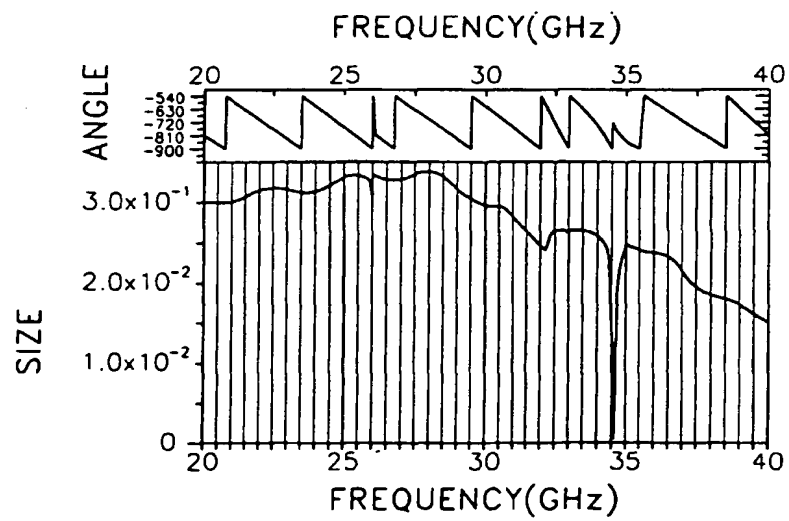


FIG. 5A

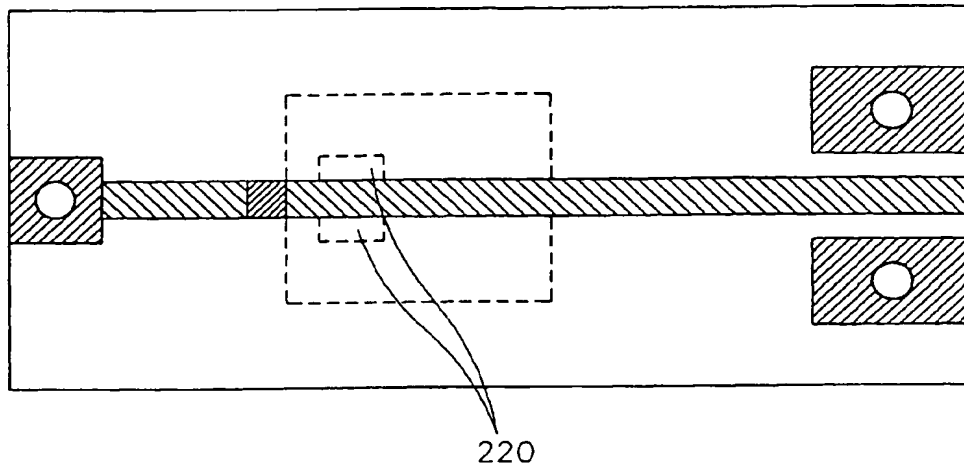
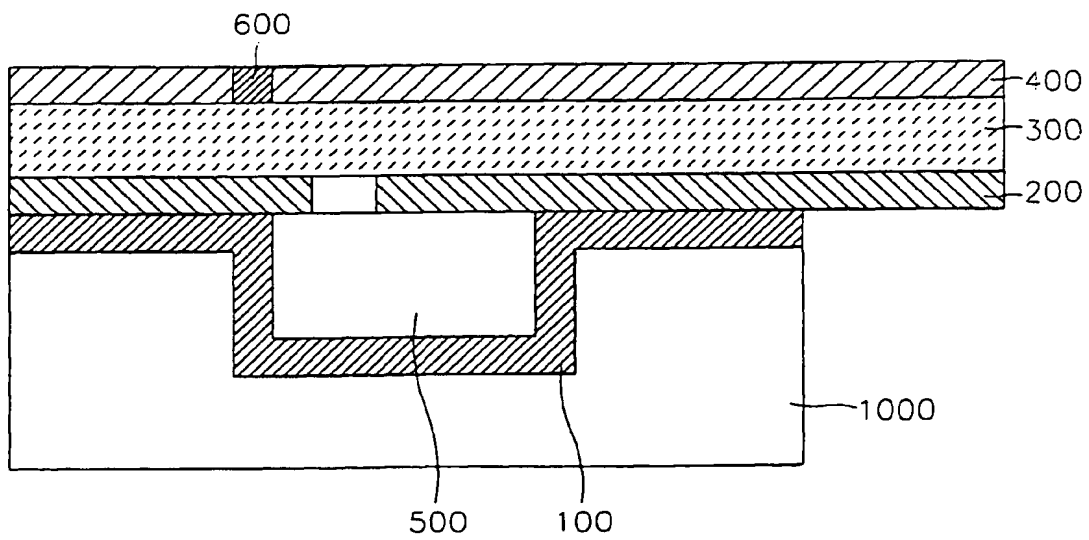


FIG. 5B



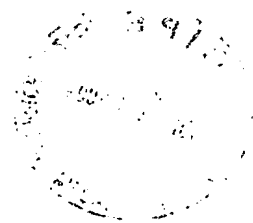


FIG. 6

